Evening co-rotating patches: A new type of aurora observed by high sensitivity all-sky cameras in Alaska

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[1] We observed an interesting auroral event at Poker Flat Research Range (PFRR, MLAT ~65.5°) using an all-sky imaging system. This aurora, which appeared in the evening (16–19 MLT) during a geomagnetically quiet period, maintained its patch structure and position for more than 40 minutes. These patches were distinct in OI 557.7-nm and N_2^+ 427.8-nm emissions. At this time, PFRR was located at a lower latitude region than the auroral oval. An extended plasmasphere was observed a few hours beforehand with the Akebono satellite in the afternoon sector. This evidence suggests that the particles causing this aurora precipitate from the extended duskside plasmasphere. We believe that the imaging observation from the ground using our technique is an effective method for investigating dynamics around the plasmapause, a still partially-unexplored region of space. *INDEX TERMS:* 2704 Magnetospheric Physics: Auroral phenomena (2407). **Citation:** Kubota, M., T. Nagatsuma, and Y. Murayama, Evening co-rotating patches: A new type of aurora observed by high sensitivity all-sky cameras in Alaska, *Geophys. Res. Lett.*, *30*(12), 1612, doi:10.1029/2002GL016652, 2003.

1. Introduction

[2] Plasmasheet plasma serves as a major source of auroral precipitating particles. Because the movement of this plasmasheet plasma is greatly affected by electric and magnetic fields in the magnetosphere, aurorae observed from the ground cannot stay at the same place in the sky for a long time [*Davis*, 1971]. During a geomagnetic substorm, auroral intensity and formations dynamically change under the influence of magnetic and electric field disturbances. During quiet periods, auroral structures drift owing to magnetospheric convection [*Nakamura and Oguti*, 1987]. The direction of the convection projected on the Earth's thermosphere in the evening sector, is usually westward. Therefore, auroral structures observed from the ground in the evening should drift westward.

[3] Poker Flat Research Range (PFRR) (geographic 65.1°N, 147.4°W, magnetic latitude ~65.5°), where we installed our all-sky imaging system is usually located in a lower latitude region than the auroral oval in the evening sector, so, we had not anticipated the presence of distinct auroral events above PFRR in the evening during geomagnetically quiet periods. However, on the evening of 27 October 2000 we observed an unexpected aurora that had discrete patch structures, continued for a few hours, and had many other interesting features. In this paper, we present an outline of our instruments and observations in the next section, describe the detailed observational results in Section 3, and discuss the mechanism of this event in comparison with recent studies in Section 4.

2. Instruments and Observations

[4] We used two all-sky imagers (CRL-ASIs) developed by the Communications Research Laboratory [*Kubota et al.*, 2002]. The CRL-ASI consists of a fisheye lens (f = 6 mm, F/1.4), a telecentric lens system, a filter turret, a bare CCD camera (512 × 512 back-illuminated), and a personal computer for operation. It covers a field-of-view (FOV) of 180°. Because the filter turret contains five interference filters, we can observe up to ten kinds of aurora/airglow emissions using the two CRL-ASIs. Sensitivity of them and nonuniformity in their image planes were calibrated using an integrating sphere facility [*Okano et al.*, 1998]. Techniques for obtaining absolute intensity distributions of aurora/airglow emissions from the CRL-ASI observation data are described by *Yamamoto et al.* [2002]. The two CRL-ASIs were installed at PFRR, and observations have been conducted daily since October 2000, except for full-moon periods and the period of the midnight sun between the end of April and September.

3. Observational Results

[5] On the night of 27 October 2000, we observed an unusual auroral event. This aurora, which had already appeared all over the sky at the observation start time of 03:00 UT, consisted of discrete patches accompanied by ray structures. The patches moved very slowly. In particular, they maintained their shapes and positions from 03:20 to 04:00 UT (Figure 1). Namely, these patches were co-rotating with the earth during this period. After that, they started to drift eastward, changed their drift direction to westward at 05:00 UT, and disappeared at about 06:00 UT. Because a relation between magnetic local time (MLT) at PFRR and universal time (UT) is given by MLT≃UT-11 hr, the auroral appearance time of 03–06 UT is equivalent to the evening time of 16–19 MLT on the preceding day. Considering these points, we named this auroral event Evening Co-rotating Patch (ECP) aurora.

[6] A few patches within the ECP aurora were pulsating with a period of ~12.5 min (not shown), but most of the patches kept their intensity for a few hours. Time resolutions for the 557.7-nm and other emissions were 2.5 and 5 minutes, respectively. Figure 2a shows time variations of the 557.7-nm aurora emission intensity along the geomagnetic meridian line (NS-keogram) made from the all-sky images. In the strict sense, most of the patches in the ECP aurora, which can be seen as horizontal stripes between 03

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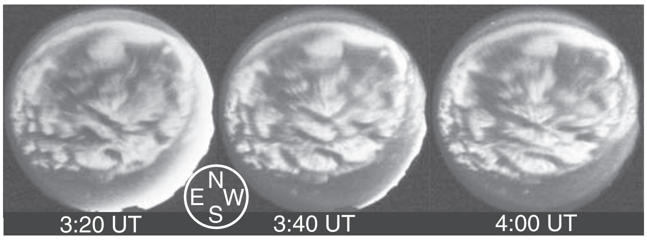

Figure 1. All-sky images of atomic oxygen (557.7-nm) aurora taken every 20 minutes from 03:20 UT to 04:00 UT. Exposure time is 3 seconds for every image. Each image has been processed by histogram equalization methods to make the auroral structures conspicuous. The bright area near the southwest edge is caused by dusk twilight.

and 06 UT, were slowly moving southward with a speed of ~5 m/s until 05 UT. After 06 UT, a bright aurora region corresponding to the auroral oval appeared near the northern edge of the plot, and started to move southward increasing in intensity at 10 UT. This suggests that the ECP aurora existed in a lower latitude region than the auroral oval. Figure 2b shows time variations of the same emission along the geomagnetic latitude line (WE-keogram). It indicates that zonal drift speeds of the auroral patches fluctuated between 03 and 06 UT as mentioned in the above paragraph. As an example, consider a patch near the zenith; it had been moving to the westward with a speed of ~40 m/s at the observation start time of 03:00 UT, and hovered from 03:20 UT to 04:00 UT. After that, it started to drift eastward with a speed of ~30 m/s, suddenly changed the drift direction to westward at 05:00 UT, and disappeared at about 06:00 UT. A westward drift speed in the last phase was about 60 m/s. Because the surface of the earth is moving to the eastward with a speed of ~200 m/s at 65° latitude by rotation of the earth, the patch drift velocity in the last phase

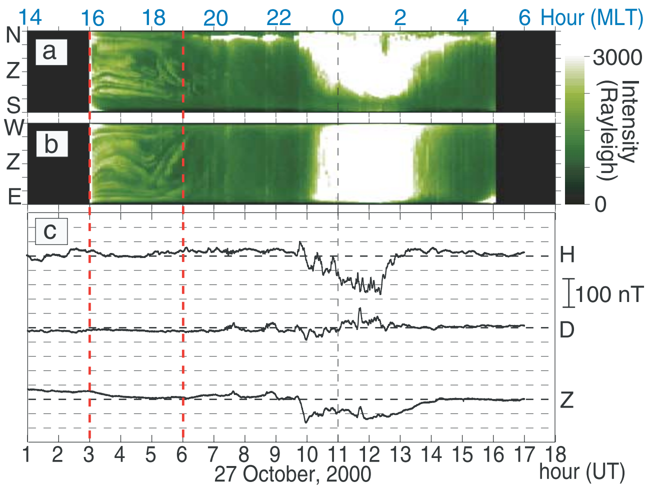

Figure 2. (a) Time sequence of 557.7-nm emission intensity along the geomagnetic meridian line, which is made from vertical (North-South) slices of the all-sky images. The ECP aurora can be seen between 3 and 6 UT, as indicated by red dashed lines. (b) Time sequence of 557.7-nm emission intensity along the geomagnetic latitude line, which is made by horizontal (West-East) slices of the all-sky images. (c) Time variations of geomagnetic field.

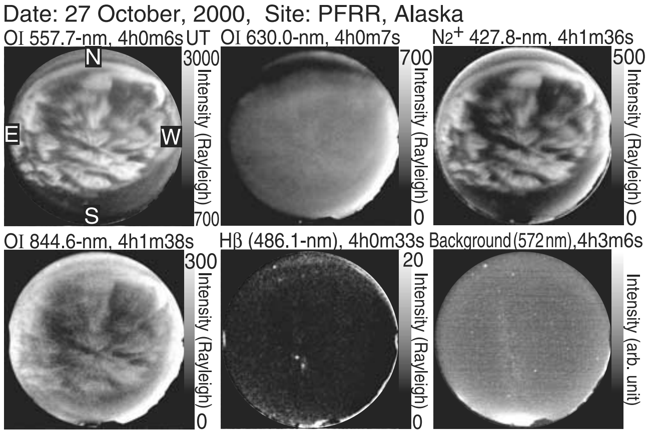

Figure 3. All-sky images of six different wavelengths observed by CRL-ASIs during the 04:00–04:05 UT period on 27 October, 2000.

is converted to about 140 m/s in the GSE coordinates, which is equivalent to 70% of the co-rotation velocity.

[7] Figure 2c shows geomagnetic field variations. During the ECP aurora, geomagnetic activity was very quiet relative to the type of magnetic activity usually associated with aurora, as exemplified by the geomagnetic variations after about 10 UT. The AE and Kp indexes (not shown) were also very small (about 50 nT and 0 +, respectively), when the ECP aurora appeared. These facts indicate that the earth's magnetosphere was not disturbed during the ECP aurora.

[8] Figure 3 shows images of OI 557.7-nm, OI 630.0-nm, Hβ, N_2^+, OI 844.6-nm, and background (572.3-nm) observed almost simultaneously at 04 UT. In the image showing background continuum intensity, there was no patch structure, while some bright stars and the Milky Way were visible. This fact shows that the sky was very clear with no clouds at this time. The patch structures of the ECP aurora were distinct in the OI 557.7-nm and N_2^+ emissions, but indistinct in the OI 844.6-nm emission. In the OI 630.0-nm and proton Hβ emissions, there were no patch structures. The maximum emission intensity of the ECP aurora at 557.7-nm was about 3 kR. It is known that the N_2^+ (427.8-nm) emission is effectively excited by relatively high-energy electrons of ~10 keV, and the OI 630.0-nm auroral emission is mainly excited by electrons of lower than several keV [*Semeter et al.*, 2001]. The emission features mentioned above indicate that the ECP aurora was caused by electron precipitation at energies greater than several keV.

[9] Figure 4 shows a comparison between horizontal distributions of the ECP aurora observed by the ground-based CRL-ASIs, magnetospheric parameters and particle precipitation observed by a DMSP satellite, and electron density observed by the Akebono satellite [*Oya et al.*, 1990]. Figure 4a indicates that the ECP aurora existed in a band-like region between 64° and 67° geomagnetic latitude, which was approximately equivalent to the region between L = 5 and 8 Re. At this time, a DMSP satellite passed near the Alaskan area and observed precipitating particles with typical auroral energies. Observed energy (Figure 4b) show intermittent electron precipitation between 64° and 67° geomagnetic latitude. However, significant ion precipitation was not seen in this area. The energy range of these precipitating electrons was above a few keV. The drift

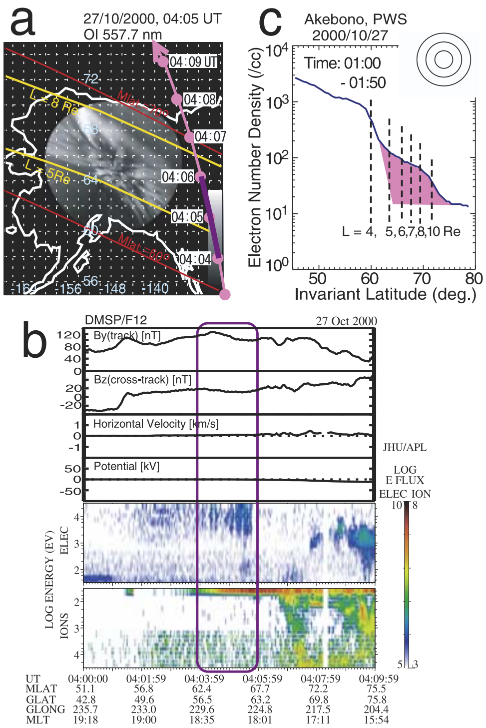

Figure 4. (a) Two-dimensional distributions of 557.7-nm emission intensities at 04:05 UT projected to a geographic map. We assume for the projection that the emission height as 110 km. Red lines show geomagnetic latitude and yellow lines show L = 5 and 8 Re calculated using the IGRF model. Pink dots and a thick line indicate foot points of the DMSP F12 satellite during the 04:03–04:09 UT. (b) Variations of the in situ magnetic fields, drift velocities, potential, and energy spectra of the precipitating electrons and ions observed by the DMSP satellite during the 04:00–04:10 UT. (c) Electron density observed by the Akebono satellite.

velocity obtained by DMSP ion drift meter (Figure 4b, the third panel) was very small (< 0.1 km/s) in this precipitation area. These characteristics of the precipitation are consistent with the auroral structure, the precipitating electrons energy, and co-rotating motions suggested from our imaging observations.

4. Discussion

[10] The fact that the ECP aurora occurred equatorward of the auroral oval suggests that the source of precipitating particles was earthward of the plasmasheet. Figure 4a shows that magnetic field lines traced from the ECP aurora extend to the area between L = 5 and 8 Re on the magnetic equatorial plane, while the inner edge of the plasma sheet is typically located at about 10 Re during geomagnetically quiet periods [*Bhatia and Lakhina*, 1978]. The electron density profile observed by the Akebono satellite reveals that the high-density electron region (i.e., the outer plasmasphere) extended out to about 70 degrees invariant latitude at about 14.5 MLT (Figure 4c). It is well-established that the average shape of the plasmasphere contains a duskside "bulge" [*Carpenter et al.*, 1993; *Lemaire*, 2001]. The observation time is about 01:30 UT, 1.5 hr before the ASI observation start time. The relationship between the UT and MLT of this observation indicates that Akebono passed over Alaska at this time. If the extended plasmasphere sampled by Akebono was co-rotating and remained for a few hours, auroral particles causing the ECP aurora must precipitate from this extended duskside plasmasphere.

[11] There exists some limited prior observational evidence for low-latitude ECP aurora such as that observed on 27 October 2000. *Oksman et al* [1981] reported sighting an unusual green (557.7-nm) aurora consisting of co-rotating cloud-like patches that lasted the whole night of 29–30 August 1978. This event occurred at much lower latitude (L = 2.7 – 3.3) than the ECP aurora. Unfortunately, imaging observations do not exist for this period. In 1977, several narrow ionization enhancements that had periodic spacing in latitude and persisted in local time were observed by the Chatanika is radar in Alaska in the evening [*Vondrak et al.*, 1983]. The occurrence time and location were very similar to those of the ECP aurora, but the horizontal features of the phenomena were not clarified because no ground-based imaging observations were made. Other ground-based observations of similar events were not found.

[12] A possibly related phenomenon is the occurrence of "detached arcs" of aurora. In the 1970s, the ISIS-2 satellite observed detached arcs which often appeared in the lower side of the auroral oval in the evening sector [*Anger et al.*, 1978; *Wallis et al.*, 1979]. These detached arcs centered mainly over the Alaska sector. It was suggested that precipitating electrons had greater energies in comparison with the usual diffuse aurora. They were not correlated with Kp and DST. It seems likely that the ECP aurora is the same phenomena as the detached arcs of *Anger et al.* [1978], because the occurrence time, geomagnetic latitude, and precipitating electron energy of both phenomena are very similar. Geomagnetic conditions seem to be different between two phenomena. We suppose a reason for this difference as follows. During geomagnetically active periods, auroral oval tends to move to a lower latitude region. The ECP aurora in a subauroral region, which is above Alaska during quiet periods, also moves to an even lower latitude region and is getting unobservable from PFRR.

[13] Subauroral proton arcs in the afternoon sector during geomagnetically disturbed periods, which observed by the IMAGE satellite, are shown by *Burch et al.* [2002]. The occurrence time and location were very similar to those discussed in this paper. However, in our case, the proton auroral emission was not observed by the CRL-ASIs during the ECP aurora (Figure 2).

[14] From a statistical analysis of the ISIS-2 data, *Moshupi et al.* [1979] showed that the occurrence frequency of detached arcs of *Anger et al.* [1978] was 26% between 225° and 270° corrected geomagnetic longitude and 17 and 19 MLT. In conducting imaging observations using CRL-ASIs over two winter seasons, we often observed auroral events similar to the ECP aurora in the evening sector during geomagnetic quiet periods. However, the typical emission intensities of these auroras were less than 1 kR at 557.7-nm, much weaker than the usual auroral intensity. This seems to be one reason that ECP aurorae have not been observed by optical instruments on the ground such as panchromatic all-sky cameras. The monochromatic CCD

imaging technique we used in this study was developed for observing faint airglow in the mid-latitude region [e.g., *Taylor et al.*, 1995; *Kubota et al.*, 1999]. This system is characterized by high sensitivity and accurate focusing adjustment, and thus is suitable for observing weak aurorae.

[15] The ECP aurora occurs in the MLT evening time. In Alaska, magnetic local time lags behind geographic local time by two hours, and therefore, optical observations of MLT evening aurorae are not obscured by sunshine. In contrast, Europe is unsuitable for the MLT evening optical observations, because the geographic local time lags behind the magnetic local time. This kind of geographical restriction is another reason that optical observations of the ECP aurora have been few.

[16] In the ISIS-2 observation, some detached arcs observed on two successive passes (2 hours apart). The arcs observed on successive passes often had similar shapes, however, their geographic positions usually did not coincide. On this account, they considered that the detached arcs do not co-rotate [*Moshupi et al.*, 1979]. In our observation, the ECP aurora above Alaska monitored consecutively. This observation showed that motion of the patches was very slow, especially from 03:20 UT to 04:00 UT. In further analysis, It is expected that detailed motions of each and every patch structure of the ECP aurora will be investigated. It shows that the ground-based imaging observation would offer advantages in spatial resolution and observation duration.

[17] *Wallis et al.* [1979] suggested that the mechanism of the detached arcs of *Anger et al.* [1978] is as follows: Residual plasma sheet electrons injected to the inner magnetosphere during a past geomagnetic substorm are partially precipitated by pitch angle scattering in the evening sector as they drift into detached plasmasphere regions. The Akebono observation of the extended plasmasphere a few hours before the ECP aurora observation supports this idea. *Titova et al.* [1998] and *Pasmanik et al.* [1998] have suggested that a significant pitch angle isotropization of energetic electrons due to the cyclotron wave-particle interactions occur near the cold plasma density gradient. Therefore, we expect that the patch structure of the ECP aurora is related to the density (gradient) distribution of cold plasma in the expanded plasmasphere. For further investigation, a comparison between the ECP aurora observations and plasmasphere imaging by the EUV instrument on the IMAGE satellite [*Sandel et al.*, 2000] will be effective.

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